Resistive switching and ferroelectricity in HfO_2 thin films

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HfO_2 is a unique material that can demonstrate resistive switching and ferroelectricity in thin films. Resistive switching is observed in metal-insulator-metal structures and strongly depends on the choice of electrode materials. Resistive switching occurs due to formation and rupture of conductive filaments in the insulating layer. According to the choice of electrode materials conductive filaments can be made of oxygen vacancies or metallic. HfO_2 thin films for observation of resistive switching are traditionally amorphous. For observation of ferroelectricity in HfO_2 thin films, they, conversely, should be crystalline, and the effect does not depend that much on the choice of electrode materials as resistive switching does.

For observation of the resistive switching effect in HfO_2 thin films, Pt and TiN are traditionally chosen as electrode materials. With such a choice of electrode materials (inert Pt and active TiN) conductive filaments are made of oxygen vacancies. Al_2O_3 thin layer deposited by Atomic Layer Deposition (ALD) can be introduced between Pt and HfO2 layers to enhance the resistive switching effect [1]. In our case the basic device structure is Pt/HfO_2/TiN. Pt and TiN are deposited by magnetron sputtering, HfO_2 is ALD deposited. The ALD deposition temperature varies from 150 to 250 °C, different thicknesses from 5 to 25 nm are investigated. Different annealing temperatures (up to 300 °C) and times (up to 30 min) of annealing of the resistive switching layer in oxygen are also investigated. Bipolar resistive switching behavior with positive set and negative reset has been found (the bottom electrode is grounded). Although the switching voltage varies from device to device, the overall uniformity level is found to be acceptable. Different compliance current levels during set process and different stop voltage levels during reset process are implemented to achieve different resistance states.

As it was mentioned before, ferroelectricity in HfO_2 thin films does not depend that much on the choice of electrode materials as resistive switching does, but, as the film should be crystalline in this case, not amorphous, it strongly depends on the crystallinity of the underlying layer. Another thing that greatly affects the effect is doping of HfO_2 thin films with different dopants at different doping concentrations. Thus, recently Wei et al. discovered a ferroelectric rhombohedral phase in well-oriented $Hf_{0.5}Zr_{0.5}O_2$ thin film [2], showing the presence of ferroelectricity in other phase besides the well-known orthorhombic polar phase (Pca21) [3, 4]. In the present study, the epitaxial growth of Al-doped HfO_2 on different oriented $La_{0.7}Sr_{0.3}MnO_3$/$SrTiO_3$ substrates is reported. The well-oriented films, which under the compressive/tensile strains depend on the lattice change, show different piezoresponse by piezoresponse force microscopy (PFM). The film growth on (111)-oriented substrate shows the largest electromechanical effect, and no wake-up cycling is required. The results, with the analysis of structure characterizations, explore the possible ferroelectric phase and the corresponding properties in Al:HfO_2 thin film.

1. Z. Chen, F. Zhang, B. Chen, et al., *Nanoscale Research Letters* **10**, 130 (2015).
2. Y. Wei, P. Nukala, M. Salverda, et al., *Nature Materials* **17**, 1095 (2018).
3. J. Muller, T.S. Boscke, U. Schroder, et al., *Nano Letters* **12**, 4318 (2012).
4. M.H. Park, T. Schenk, C.M. Fancher, et al., *Journal of Material Chemistry C* **5**, 4677 (2017).